Peaking and Net-Zero for India's Energy Sector CO_2 Emissions

An Analytical Exposition

Vaibhav Chaturvedi

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Summary

Climate change mitigation is a critical global challenge. Many large economies have announced their ambition of a net-zero year, that is, the year their economies will achieve net-zero greenhouse gas (GHG) emissions. Although India has demonstrated climate leadership on several occasions, whether it will make an announcement in this regard is being closely observed. This issue brief highlights that for a rapidly developing economy, the choice of a peaking year must be explicit in the selection of a net-zero year. It presents an analytical exposition to better understand key variables, which would impact the choice of peaking and net-zero years for India's energy sector-related carbon dioxide emissions, accounting for 88 per cent of India's total GHG emissions, including land-use change emissions.

The brief focuses on insights related to four alternative scenarios: 2030 peak–2050 net-zero, 2030 peak–2060 net-zero, 2040 peak–2070 net-zero, and 2050 peak–2080 net-zero. These scenarios are based on an India-specific analysis as well as comparison of key variables of some major economies. The key indicators for the 2050 world regarding the above-mentioned alternative scenarios are presented, including the required reduction in emission intensity of gross domestic product, share of electric vehicles, and share of renewable energy in electricity generation, among other variables, for each scenario with and without carbon capture and storage (CCS). The analysis shows that rapid economic growth is one of the most important variables that needs to be better understood in the choice of peaking and net-zero years.

Along with insights for alternative peaking year and net-zero year scenarios, the analysis shows that if 2050 were chosen as a net-zero year and if CCS technology were commercially unviable by then, this would imply that:

- **the share of fossil energy** in India's primary energy mix would have to reduce to 5 per cent in 2050 from 73 per cent in 2015;
- 83 per cent of electricity would have to be generated from **non-hydro renewable energy sources** by 2050, up from 10.1 per cent in 2019;
- **biofuels** would have to account for 98 per cent of India's oil use in 2050 compared to negligible share currently; and
- over two-thirds of India's industrial energy use and new vehicle sales would have to be **electrified**, compared to 20.3 per cent share of electricity in industrial energy use and negligible share in transport energy use as of now.

Even a significant decline in the cost of renewables-powered hydrogen would be unable to change the character of the net-zero energy systems described above.

The choice of a net-zero year in 2050 would present an opportunity for an economic growth paradigm focused on green infrastructure and sustainable investment — and avoid lock-in into long-term fossil fuel assets. At the same time, India would have to confront critical trade-offs related to increasing cost of electricity for household energy use, increasing passenger travel charges in rail travel, fiscal challenges for coal-dependent states, job losses for over half a million coal mining workers, and the shifting geopolitics around energy trade and the energy transition.

The key considerations in the selection of peaking and net-zero years should be the average per capita income, economic growth rate, a 'reasonable' pace of transition determined by the gap between peaking and net-zero years, possibility of lock-ins and stranded assets, the cumulative emissions across the alternative peaking year–net-zero year combinations, and the economic trade-offs as presented here. The selected combination should provide India sufficient time to develop while ensuring that the climate impact is minimised.

1. Introduction

Emission mitigation is a key policy objective for policymakers in India and the world. In 2020, many countries and regions, including China, the European Union (EU), Japan, Korea, and the UK, announced their net-zero ambitions (Varro and Fengquan 2020; Croatian Presidency of the Council of the European Union 2020; Reuters 2020; The Government of the Republic of Korea 2020; The Government of the United Kingdom 2020). With President Biden in office, the US is also expected to announce 2050 as the target year for achieving net-zero emissions for the US economy if he follows through on his pledge (Birol 2021). The Paris Agreement calls for limiting the global temperature increase to "well below 2 degrees Celsius" relative to pre-industrial levels. This makes it imperative that the world as a whole and individual countries begin their transition to a 'net-zero' greenhouse gas (GHG) emitting economy as early as possible. Achieving this target implies a significant increase in the rate of reduction of global emissions, a challenge for many countries. This is especially true for low-middle-income and rapidly growing economies such as India, which need to address the development aspirations of their citizens while trying to reduce emissions simultaneously.

India is one of the fastest growing economies in the world. The per capita carbon dioxide emissions, 1.82 tCO_2 in 2016, was much lower than the global average of 4.55 tCO_2 (World Bank 2021). Owing to its population and size of the economy, India became the fourth highest emitter in 2017 (UNEP 2019). Because India's emissions are expected to continue to increase, its emission mitigation strategy and targets are crucial in the global climate debate.

The IEA in its recently released India Energy Outlook explores the 'net-zero' question (IEA, 2021a). While this analysis is useful, it is constrained by the exploration of a single scenario, namely net-zero by mid-2060s. **In order to inform this critical debate in India, it is important to present alternative scenarios and highlight the trade-offs among these.** Moreover, the IEA report does not dwell either on the question of peaking year, or the character for such a net-zero future, with the key insights from the report mainly focused on intermediate years and required transitions in the next two decades on the path to achieving net-zero by mid-2060s.

While the world awaits India's announcement on a net-zero year, such a statement cannot be delinked with the choice of a peaking year. For developed economies already on a declining emissions trajectory, the peaking year is not a discussion agenda. However, for fast-growing economies with a rising emissions trajectory, the need to understand the key variables that impact the choice of a peaking year is as critical as the determinants for the choice of a net-zero year. **The choice of a peaking year is implicit in India's net-zero discussion, and the two need to be analysed together.**

A crucial question is: Can India peak its emissions within the next couple of decades and then continue a net-zero trajectory? The analytical exposition in this brief aims to discuss the underlying variables that will impact India's peaking year and the journey toward net-zero emissions. The numbers in this brief refer to India's energy and industrial process-related carbon dioxide emissions, which accounted for 88 per cent of its total GHG emissions in 2016, including land use, land-use change, and forestry (Ministry of Environment, Forest and Climate Change 2021), and the implications and insights are essential for India's consideration of a peaking year and net-zero target.

Box 1 presents an analytical exposition of the meaning of peaking emissions based on three underlying variables: gross domestic product (GDP) growth, rate of change in primary energy intensity of GDP, and rate of change of emission intensity of primary energy. The peak emissions can be explained by the combination of these three variables. For a growing economy such as India, the key insight from the analytical exposition is as follows:

As long as India's GDP continues to increase at a rate higher than the sum of the decline in primary energy intensity of GDP and emission intensity of primary energy, India's carbon dioxide emissions will not peak.

Box 1: A simple arithmetic expression to explain peak in emissions

Emissions can be expressed in terms of three underlying variables: gross domestic product (GDP), energy intensity of GDP, and emission intensity of energy, also known as the Kaya identity (Kaya and Yokobori 1997; Hwang et al. 2020).

E = GDP × (PE/GDP) × (E/PE),
where E is emissions in metric tons of carbon dioxide equivalent, PE is primary energy in mtoe, and GDP is gross domestic product in trillion USD.

Hence, change in emissions can be expressed as:
ΔE = ΔGDP + Δ(PE/GDP) + Δ(E/PE) -- (1),
where ΔE is the growth rate of emissions, ΔGDP is the GDP growth rate, Δ(PE/GDP) is change in primary energy intensity of GDP, and Δ(E/PE) is change in emission intensity of primary energy.

For example, between 2005 and 2014, the annual rate of change of these variables for India was (World Bank, 2021):
ΔE = 6.95%, ΔGDP = 6.61%, Δ(PE/GDP) = −1.19%, and Δ(E/PE) = 1.53%.

Peak in emissions implies that the rate of growth in total emissions is negative or zero, not just for one period but decisively so for all subsequent years after the peak is achieved, i.e.
ΔE <= 0
==> ΔGDP + Δ(PE/GDP) + Δ(E/PE) <= 0

Moving from a peaking year to a net-zero year implies that the change in emissions cannot be zero, but has to be negative, i.e. emissions are not stabilising at a particular value (i.e., ΔE = 0), but are continuously declining. In other words,
ΔGDP + Δ(PE/GDP) + Δ(E/PE) < 0

or

ΔGDP < (Δ(PE/GDP) + Δ(E/PE)) -- (2),

assuming that emissions will be on a continuously declining trajectory beyond peaking till net-zero is achieved.

With a move toward renewables in the electricity generation sector, higher penetration of electric vehicles, and electrification of end-use sectors, we can expect intensity of primary energy to decline continuously, that is, Δ(E/PE) < 0*

Similarly, with gains in energy efficiency across end use and transformation sectors, the primary energy intensity of GDP would also decline continuously over the next few decades, i.e. Δ(PE/GDP) < 0, even if the rate of decline is slower in the future as more potential for energy efficiency-related gains is harnessed.

However, the GDP is expected to grow, i.e. ΔGDP > 0.

Thus, for understanding the peaking year for emissions, equation (2) for India can be expressed as:

ΔGDP < | Δ(PE/GDP) + Δ(E/PE) | -- (3).

Hence, as long as India's GDP continues to increase at a rate higher than the sum of decline in primary energy intensity of GDP [Δ(PE/GDP)] and emission intensity of primary energy [Δ(E/PE)], India's carbon dioxide emissions will not peak. The GDP growth rate needs to be lower than the sum of the other two components of the Kaya identity. In other words, the faster the economy grows (there is no reason to expect that policymakers would not wish to promote rapid economic growth and associated poverty reduction), the larger the decline in energy intensity and/or emission intensity needs to be. This is the challenge for India and other fast-growing economies.

** An exception could be if India's manufacturing sector grew at a fast pace and is fueled by fossil energy sources. In this case, emission intensity of primary energy can increase. However, this would in all probability be inconsistent with a trajectory associated with peaking and further decline toward net-zero.*

2. When could India's carbon dioxide emission peak?

The year for peak emissions and achieving net-zero is a policy choice. Here, we provide an overview of the following four alternative scenarios for India's peaking and net-zero years: 2030 peak–2050 net-zero, 2030 peak–2060 net-zero, 2040 peak–2070 net-zero, and 2050 peak–2080 net-zero. Based on equation (3), **as given in Box 1, we can determine the effort required for peaking as follows:**

GDP growth rate – sum of decline in PE intensity of GDP and decline in emission intensity of PE = effort gap

The higher the effort gap, the higher the effort required for emissions to peak. Table 1a lists our estimates for the gap in the reference scenario[1] for the years immediately after the peaking year.

Table 1a Effort gap in the reference scenario

	India			China
	2030-35	2040-45	2050-55	2030-35
Real GDP growth (ΔGDP)	7.1%	5.6%	4.1%	3%
Change in PE intensity of GDP (Δ(PE/GDP))	-2.9%	-2.5%	-2.2%	-2.2%
Change in emission intensity of primary energy (Δ(E/PE))	-0.31%	-0.29%	-0.23%	-0.2%
Effort Gap (ΔGDP - | Δ(PE/GDP) + Δ(E/PE) |)	3.9%	2.6%	1.7%	0.6%

Source: Author's analysis based on the Global Change Analysis Model[2] (GCAM, CEEW version).
Note: PE has been measured in direct equivalent terms.

If India chose to peak in 2030, then from the next year onwards, it would have to ensure that the combined

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Compared to India, bridging the gap after its peaking year is much easier for China.

rate of decline in the primary energy intensity of GDP and emission intensity of primary energy is higher than the GDP growth rate, and the effort gap would have to be bridged. Hence, it is clear from Table 1a that, with a natural decline in the GDP growth rate, the effort gap declines over time, and bridging this gap becomes easier in later years. However, if the peaking year is 2025, the effort gap would be even higher.

Compared to India, bridging the gap after its peaking year is much easier for China, as its real GDP growth rate post-2030 is expected to be much lower and the per capita income is expected to be much higher. In other words, China aims to peak emissions at a much higher level of development.

Table 1b Effort gap in the low GDP growth scenario

	India			China
	2030-35	2040-45	2050-55	2030-35
Real GDP growth (ΔGDP)	4.8%	3.9%	3.3%	3%
Change in PE intensity of GDP (Δ(PE/GDP))	-2.4%	-2.0%	-1.9%	-2.2%
Change in emission intensity of primary energy (Δ(E/PE))	-0.22%	-0.22%	-0.28%	-0.2%
Effort Gap (ΔGDP - | Δ(PE/GDP) + Δ(E/PE) |)	2.2%	1.7%	1.1%	0.6%

Source: Author's analysis based on the Global Change Analysis Model (GCAM, CEEW version).
Note: PE has been measured in direct equivalent terms.

In a low GDP growth scenario, India's effort gap would be lower (table 1b); however, it would still be much higher than China's effort gap. The corresponding effort gaps for 2030–35, 2040–35, and 2050–55 are 2.2 per cent, 1.8 per cent, and 1.4 per cent, respectively, in

1 Reference scenario implies that the Indian economy grows in a business-as-usual (BAU) fashion. This scenario reflects the changes that are already visible in the market, such as rapidly declining cost of solar-based electricity generation and passenger electric vehicles, efficiency improvements in the end-use sectors, increased availability of natural gas in the global energy market post US shale gas discovery, and achievement of India's nationally determined contribution targets.

2 GCAM is an integrated assessment model with detailed representation of the energy systems. It models energy demand for residential and commercial building, industrial, and transportation sectors. The energy supply is modeled for all fuels across sectors, including the electricity generation and the refinery sectors. The primary energy intensity, as shown in the table, declines as consumers and businesses own and operate more efficient equipment (e.g., LED bulbs, more efficient air-conditioners and vehicles, and more efficient industrial equipment and power plants) in the future. The emission intensity of primary energy declines over time with a shift toward non-fossil energy sources in the electricity generation, electrification of transport, and industry sectors, as well as higher penetration of biofuels in the system. All these changes related to declining primary energy intensity of GDP and emission intensity of primary energy are modeled explicitly in the GCAM framework. GCAM has been developed at the Joint Global Change Research Institute (JGCRI, USA) as a community model, and is one of CEEW's in-house models.

India's low economic growth scenario. The underlying economic growth assumption under the low economic growth scenario for India during 2015–50 is 4.54 per cent compound annual growth rate (CAGR) compared to 6.16 per cent CAGR for the reference scenario. The fluctuations in emissions intensity of primary energy and primary energy intensity of GDP reflect the numerous changes in these variables across various demand, supply, and transformation sectors hidden in the aggregate number presented here.

China has sustained a high GDP growth rate for more than three decades, resulting in high per capita income and the associated emissions. As the economy grows, the rate of economic growth is expected to slow down. Continued improvements in the emission intensity of primary energy and primary energy intensity of GDP, along with lower GDP growth rates, would allow it to peak its carbon dioxide emissions in the next decade.

However, India's case is different, mainly because of the higher GDP growth rate expected for the next few decades. Although significant progress has been made in terms of the growth in renewable energy penetration in the grid, electrification of the transport sector, and energy efficiency improvements in the buildings and industrial sector, the GDP growth effect will overpower these positive developments by a large margin for the next few decades if things continue to evolve as they have in the last decade, or along the BAU pathway.

The combination of a high GDP growth rate and a continuously declining energy efficiency improvement rate implies that the rate of decline in emission intensity of primary energy for India needs to be increased drastically to overcome the effort gap and push the peak to pre-2050. This essentially means fuel switching at a fast pace across sectors. Renewables would have to accelerate much quicker, electric vehicles would have to penetrate in a large way as early as 2030, and the industrial sector would need to move away from fossil fuels to electricity as early as possible. Energy efficiency improvements across sectors, while critical, along with high renewable energy share in the power sector, will not deliver the required shift in the peak before 2050. A shift towards the manufacturing sector, as envisaged in the *Make in India* initiative, would make the transition across sectors, as discussed above, even more important as traditional manufacturing units are fossil-intensive and can negatively impact the rate of decline in emission intensity of primary energy. India needs to identify manufacturing sectors where electricity can be used as a fuel instead of fossil fuels, as well as reduce the cost of electricity to make this fuel competitive.

> **The GDP growth effect will overpower these positive developments by a large margin for the next few decades.**

> **A key determinant is the cost-effectiveness of mitigation technologies and the favourable underlying societal conditions to adopt them.**

It should be noted here that bridging this gap is not just a matter of GDP growth. A key determinant of this effort is the cost-effectiveness of mitigation technologies and the favourable underlying societal conditions to adopt them. In general, if a mitigation technology becomes cost-effective, it would be available for all countries through diffusion. The market would ensure the rapid penetration of cost-effective technologies. This has been proven by the rapid global uptake of solar photovoltaic technology and the rapid increase in electric vehicle sales worldwide. Thus, we can expect that a similar mitigation technology suite is available worldwide at any given point in time. The required pace of deployment of these technologies for moving towards a net-zero world across different countries is determined by the speed of economic growth in these regions. Faster deployment of mitigation technologies to match the rapid economic growth would imply a need for rapid systemic changes and that all underlying societal factors vital for the transition align to ensure rapid systemic change. In mature economies with a slower pace of economic growth, several underlying systems assist the required pace of transition. This may not be true for emerging economies.

3. Moving from peaking year to net-zero year

As discussed in the section above, the pace of the required transition is important and is determined by many variables. Table 2 presents a comparison of some countries that have announced their net-zero ambition with India's potential scenarios.

Table 2 Comparison of some key variables for countries with net-zero ambition and India

	China	EU	Japan	UK	US	India Sc1	India Sc2	India Sc3	India Sc4
Peaking year*	2030	1979	2004	1973	2007	2030	2030	2040	2050
Per capita CO_2 emissions in peaking year ($MtCO_2$)	9.3	9.84	9.88	11.74	19.2	1.96	2.29	3.02	3.71
Five-year real GDP CAGR post-peaking year	3%	1.5%	-0.4%#	1.1%	0.7%#	7.1%	7.1%	5.6%	4.1%
Per capita income (2017 US$, PPP) in peaking year##	29438	NA	36994	NA	55916	8779	8779	15979	25682
Net-zero Year	2060	2050	2050	2050	2050**	2050	2060	2070	2080
Years between peaking and net-zero	30	71	46	77	43	20	30	30	30
Five-year real GDP CAGR post net-zero year	0.5%	1.3%	0.6%	NA	1.0%	4.1%	3.1%	2.2%	1.5%
Per capita income (2017 US$, PPP) in net-zero year##	57139	64753	64558	NA	88459	25682	37172	49974	63135

Source: Author's analysis based on World Bank data (World Bank 2021) and Global Change Analysis Model (GCAM-CEEW version). All historical data points related to emissions and GDP were obtained from the World Bank database. All future year numbers were taken from the GCAM database. CAGR implies a compounded annual growth rate.

**Author's assessment based on historical emissions data for the EU, Japan, the UK, and the US. Apart from China, no other country has announced a peaking year. While for all other countries there appears to be a decisive decline in emissions post-peaking year, Korea has been excluded from this table as it is unclear if its emissions have already peaked or will peak in the future.*

 # In the case of Japan and the US, negative/low CAGR is due to the global economic recession during this period. In subsequent years, the CAGR of real GDP between 2009 and 2019 was 1.3 per cent for Japan and 2.3 per cent for the US.

*** US net-zero emissions year has not been formally announced yet.*

For India, the real GDP growth rate assumption (market exchange rate) has been aligned with the NITI Aayog IESS assumptions. For all other countries, SSP2 GDP growth rates were assumed. The UK has not been modelled separately in the GCAM-CEEW version used in this exercise.

Some key insights emerge from Table 2. First, the per capita emissions for all other economies, including China, are much higher than those of India, even if one assumes peaking for India in 2050. Second, India's real GDP growth rate would be much higher than any other country after their peaking years, implying a much higher effort required by India to peak and subsequently reduce emissions. Third, India would have a much lower per capita income to support the transition, even if it began the transition in 2040. Finally, the gap between the peaking year and net-zero year has been long for most countries, signifying a pace of transition that reflects a relatively less disruptive impact on energy systems and the society.

4. Can there be a balanced combination of peaking year and net-zero year that minimises challenges while minimising India's emissions?

Irrespective of the challenges emerging from economic growth for the transition to a net-zero world, India needs to take decisive action to mitigate climate change. It needs to announce peaking and net-zero years urgently. However, it is not necessary to announce the peaking year. South Korea, for instance, has just announced a net-zero year, although it is unclear whether its emissions have peaked. Although India could follow a similar approach, it would not be the best strategy. A net-zero year as far as 2070 or 2080 would not push key economic actors to take decisive actions. The peaking year is a critical marker and provides a clear policy signal to various stakeholders. Table 3 presents some key indicators for the alternative peaking and net-zero scenarios discussed in this brief. These are presented for two alternative worlds, one in which carbon capture and storage (CCS) technology is available, and other in which the world does not rely on this technology. CCS is a controversial technology, and presents a perverse incentive (a sort of moral hazard) to not do much in the near-term. Progress on this technology has been very slow, although IPCC assessments (e.g. see IPCC, 2018) highlight the importance of this technology for deep decarbonisation.

India needs to take decisive action to mitigate climate change. It needs to announce peaking and net-zero years urgently.

Table 3 Key progress indicators across alternative peaking and net-zero year combinations in 'with' and 'without CCS' scenarios

			2050			
			2030peak 2050 net-zero sc	2030peak 2060 net-zero sc	2040peak 2070 net-zero sc	2050peak 2080 net-zero sc
Decline in emission intensity of GDP (2005-2050)	24% (2005-16)[a]	With CCS	100%	95%	85%	72%
		W/o CCS	100%	95%	85%	72%
Share of non-hydro RE in electricity generation	10.1% (2019)[b]	With CCS	70%	68%	57%	28%
		W/o CCS	83%	82%	65%	28%
Share of electricity in industrial energy use	20.3% (2018)[b]	With CCS	55%	52%	41%	30%
		W/o CCS	70%	61%	43%	30%
Share of electric cars in passenger car sales	0.1% (2019)[c]	With CCS	76%	76%	76%	75%
		W/o CCS	78%	77%	75%	75%
Share of electric trucks in freight truck sales	~0% (2019)[c]	With CCS	21%	21%	11%	6.7%
		W/o CCS	67%	50%	12%	6.7%
Share of biofuels in liquid fuel	NA	With CCS	62%	30%	9%	6%
		W/o CCS	98%	30%	9%	6%
Share of fossil energy in primary energy	73.8% (2015)[d]	With CCS	31%	44%	65%	84%
		W/o CCS	5%	29%	60%	84%
Share of CCS in primary energy	NA	With CCS	37%	24%	9%	0%
		W/o CCS	0%	0%	0%	0%

Source: Author's analysis based on GCAM-CEEW for 2050 numbers.
[a] GoI (2021); [b] IEA (2021b); [c] IEA (2020); [d] IEA (2017)

The table shows that availability, or absence, of CCS would define the shape of India's energy systems, regardless of the choice of peaking and net-zero year.

The critical variables discussed in earlier sections provide an overview of one of the most important challenges for the transition as a result of economic growth. Table 3 presents what this would mean across sectors. Clearly, the effort required is very high in scenarios with an early peak and a rapid decline. The table shows that availability, or absence, of CCS would define the shape of India's energy systems, regardless of the choice of peaking and net-zero year. While there is progress on this technology, it is far from satisfactory. If this technology is not commercially available, India will have to largely get out of fossils in and beyond the net-zero year. Some fossil energy use (<5% in PE) could continue as it would be offset by bioenergy crops, which would act as a carbon sink. The share of other technologies like solar and liquid biofuels, and electrification of end-use sectors, would have to grow significantly in the absence of CCS. Electrification of industries as well as freight transport would have to happen much faster as oil and coal use would have to be phased out in the absence of CCS. Biofuels would have to play an important role, with or without CCS, although lack of availability of CCS would imply an even higher use of biofuels in India's oil supply chain. Costs of hydrogen produced from renewable sources would have to fall drastically in the next decade for it to play an important role in the net-zero future. India might not have enough land to grow bio-energy crops, which has been a concern. But in the future net-zero world, liquid biofuel would be imported by India like oil is imported today. In such a scenario, biomass-rich regions like Brazil could replace the role of West Asia as the suppliers of liquid fuels.

Although the role of sustainable lifestyles has become crucial in the transition debate, rapid technological advances as described above need to be made to

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address the challenge of decarbonisation. However, this challenge must not ignore the reality of climate change.

Delaying a peak in emissions would have a larger impact on climate change. Hence, it is critical that India does not wait until 2050 to peak its emissions. Postponing peaking and net-zero years will increase India's climate impact, which needs to be minimised to the largest extent possible. Table 4 presents the estimates of India's cumulative emissions to help us understand the comparative climate impact of these alternative scenarios.

India's numbers pale in comparison to China, the EU, and the US. Of course, if economic growth turned out to be lower and the cost of mitigation technologies declined faster than anticipated, Indian policymakers, industrial leaders, and consumers could harness the opportunity and aim to achieve net-zero as early as possible.

There would be some important economic trade-offs that India would have to deal with on the path towards achieving a net-zero year. Some benefits are clear. A decisive shift towards a 'net-zero' economy

Table 4 Cumulative emissions impact of alternative peaking and net-zero year combinations

	Scenario	Peaking year	Net-zero year	Historical CO_2 emissions 1900–2010 ($GtCO_2$)	Cumulative CO_2 emissions 2021–2100 ($GtCO_2$)
India	A	2030	2050	31	63
	B	2030	2060		80
	C	2030	2070		97
	D	2040	2070		142
	E	2040	2080		166
	F	2050	2080		216
	G	2050	2090		246
China				129	349
EU				292	69
US				344	104

Source: (1) Author's analysis based on GCAM-CEEW for all India-specific scenarios and numbers in the table, excluding historical emissions. (2) CEEW analysis for future emissions for China, the EU, and the US based on climate action tracker data (Climate Action Tracker, 2021). (3) Historical emissions for all countries/regions derived from the CAIT Climate Data Explorer (2017) dataset.
Note: Here, we present three additional scenarios for India, where the net-zero year is delayed by 10 years for 2030, 2040, and 2050 peaking year alternatives. All carbon dioxide numbers exclude non-energy carbon dioxide emissions.

While scenarios A and B are the most suitable from a climate change mitigation viewpoint, India can choose these scenarios only if substantial financial and technological support are available from other developed countries. However, given experience, this seems challenging. In contrast, postponing the peaking year until 2050 would be highly damaging from a climate perspective. To compare the above estimations of cumulative carbon emissions across various peaking and net-zero year combinations for India with other regions, the 2021–2100 cumulative emissions based on their net-zero ambition would be 349 $GtCO_2$ for China, 69 $GtCO_2$ for the EU, and 104 $GtCO_2$ for the US. When historical emissions are included in the comparison,

> **In contrast, postponing the peaking year until 2050 would be highly damaging from a climate perspective.**

provides an opportunity to pivot economic growth around green infrastructure creation. Be it generation and transmission infrastructure for non-fossil energy sources, or an even larger electricity system for rapid electrification of various end-use sectors. Early shift would ensure avoidance of lock-ins. **There would, however, be some trade-offs as well:**

Electricity prices for households would increase: The cross-subsidy based electricity pricing regime has to be dropped for a rapid electrification of industrial energy use. This would mean household electricity prices would have to be increased. In absence of this, government's budgetary burden could increase significantly as the financial viability of distribution companies will be further hit.

Railways passenger tariff would increase: Coal freight is significant for the revenues of Indian Railways

(IR). A net-zero India means that the IR would lose this significant source of revenue, forcing it to either raise revenue through freight or passenger sources. Freight charges are already high in order to subsidise passenger fares. In all likelihood, millions of passengers dependent on subsidised railway charges would face increasing prices to compensate for the loss of revenues from transporting coal.

Coal-dependent states would face fiscal challenges: Some states in India, particularly in the eastern belt such as Odisha and Jharkhand, generate a sizeable source of their state government revenue from the energy sector. Going out of fossils, specifically coal, would mean that these states not just think about a new economic development paradigm drastically different from their current economic approach, but are well onto that pathway by 2050.

Coal sector jobs would be lost: Over half a million coal mining workers would have to be provided with alternative gainful employment opportunities commensurate with their skills or retrained for work in other related energy sectors or be given severance packages in the event of shut down of this sector. Coal India Ltd. would have to wind down operations, at least in its current avatar.

Geopolitics would shift: A net-zero target would also bring about a dramatic shift in the geopolitics of energy. India could start importing biofuels from Southeast Asia or South America, which are rich in water resources. This will break transform existing energy relationships, such as with West Asia, and create new opportunities as well as tensions. The reliance on critical minerals, which are used in clean energy and clean mobility sectors, would also grow.

Along with economic growth and the economic trade-offs presented above, **there are four critical considerations in choosing peaking and net-zero years. First** is the duration between a peaking and a net-zero year. In general, countries take at least 30–40 years to transition from a peak to a net-zero year (Table 2). This pace of transition appears to be manageable. Several underlying societal factors need to be adjusted to ensure a smooth and equitable transition. **Second** is the cumulative emissions associated with each peaking and net-zero year combination. A delay in peaking, generally speaking, does imply an increase in the cumulative emissions between the peaking and net-zero year. **Third** is the possibility of stranded assets. The greater the delay, the higher the possibility of long-term lock-ins and stranded assets in the future, as well as higher cumulative emissions. The **fourth** is the availability of an economically viable mitigation technology set, particularly biomass, carbon capture and storage (bio-CCS) and/or green hydrogen. The larger the portfolio available for mitigation, lesser is the over-reliance on one or two key technology options. As shown in table 3, CCS gives an option to continue with fossils to some extent. Bio-CCS gives an option to emit in some sectors, which are 'netted' through negative emissions from the bio-CCS technology.

5. Conclusion

Climate change impacts are pushing policymakers toward meaningful near-term actions to reduce emissions. Some large countries have announced their ambition to achieve net-zero economies in the future. This provides a critical and clear policy signal for actors to rally around and increase the pace of transition. India is an influential nation in the climate change debate, and the world keenly awaits its decision on net-zero.

This provides a critical and clear policy signal for actors to rally around and increase the pace of transition.

This brief presents a simple analytical formulation to better understand the challenges associated with alternative combinations of peaking and net-zero years for India. First, it highlights that for a rapidly developing economy, the choice of peaking year is implicit in the selection of a net-zero year; hence, it is important to assess peaking year to inform the decision-makers who will be impacted by the transition.

The analytical formulation shows that the 'effort gap' is significantly impacted by the economic growth rate. For India, peaking in 2030 would be very challenging given the expected economic growth rates for at least the next two decades. With such growth rates, the rate of fuel shift toward non-fossil energy and decrease in primary energy intensity of GDP needs to be much faster compared to other countries like China, which are going to peak when their economies are much larger and their economic growth rates are comparatively much lower.

The rate of expected GDP growth would make it very challenging for India to have an early peak.

In summary, the rate of expected GDP growth would make it very challenging for India to have an early peak, and it needs a much faster transition in terms of fuel shift across sectors in the economy compared to countries that are expected to have a lower GDP growth rate in the next few decades, such as China. These shifts need a step-change in how India's demand and supply sectors operate and, hence, would have significant near- and long-term costs. While a near-term transition from peak to net-zero presents opportunities for a green infrastructure driven economic growth agenda, it would also present many critical trade-offs amplified by the rapid pace of required transition towards a net-zero world for a low-income yet rapidly growing economy. It is important to recognise the trade-offs so that appropriate domestic measures can be taken. Moreover, this would require active support for India's transition from and in collaboration with advanced economies in terms of financial invesments and technology transfer/co-development. India needs to invest in technologies that can reduce energy intensity and emission intensity, and would need international support in order to pursue more aggressive route to decarbonisation. Clearly, India will need to do more than its fair share for the world to achieve the "well below 2 degrees Celsius" target.

It is important to recognise the trade-offs so that appropriate domestic measures can be taken.

The key considerations for selecting peaking and net-zero years should be per capita income, economic growth rate, a 'reasonable' pace of transition determined by the gap between peaking and net-zero years, possibility of lock-ins and stranded assets, and the cumulative emissions across the alternative peaking year–net-zero year combinations. The chosen combination should provide India sufficient time to develop and ensure that the climate impact is minimised. It is clear that the transition towards decarbonisation that is already underway needs to be accelerated urgently to ensure the bending of emissions curve below the BAU trajectory. An ambitious decarbonisation plan should not be ruled out; however, it would not be possible without significant and steady financial and technical support from the developed world.

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Vaibhav Chaturvedi | vaibhav.chaturvedi@ceew.in

Vaibhav Chaturvedi, a Fellow at CEEW, leads the 'low carbon pathways' focus area. His research on energy and climate change policy is positioned within the integrated assessment modelling framework of the Global Change Assessment Model. Vaibhav is an alumnus of the Indian Institute of Management Ahmedabad and Indian Institute of Forest Management, Bhopal.

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Council on Energy, Environment and Water
Sanskrit Bhawan, A-10, Qutab Institutional Area
Aruna Asaf Ali Marg, New Delhi - 110067, India
+91 11 40733300 | ceew.in | @CEEWIndia | ceewIndia